

What is claimed is:

1. A method for separating M signals provided by M sources and received by an array comprising N elements, said method comprising:

generating a hybrid separation matrix as a function of:

5 time differences between receipt of said M signals by said N elements;

a spatial fourth order cumulant matrix pencil;

a spatial correlation matrix; and,

steering vectors of said M signals,

and,

10 multiplying said hybrid separation matrix by a time series matrix representation of said M signals.

2. A method in accordance with Claim 1 wherein the hybrid separation matrix is in accordance with the following equation:

15  $\hat{w}_{j,hyb} = \left| \hat{v}_j^H \hat{K}_j^{-1} \hat{v}_j \right|^{-1} \hat{K}_j^{-1} \hat{v}_j$ ; wherein,

$v_j$  is the steering vector of the  $j^{th}$  signal; and,

$K_j$  is the noise spatial covariance matrix of the  $j^{th}$  signal.

3. A method in accordance with Claim 1 wherein said spatial fourth order cumulant  
20 matrix pencil is a function of a spatial fourth order cumulant matrix.

4. A method in accordance Claim 3, wherein said spatial fourth order cumulant matrix is in accordance with the following equation:

$$C_x^4(\tau_1, \tau_2, \tau_3) \equiv \sum_{i=1}^N \text{Cum} \left[ x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3) \right], \text{ wherein:}$$

$C_x^4(\tau_1, \tau_2, \tau_3)$  is said spatial fourth order cumulant matrix having a first time lag,  $\tau_1$ , a second time lag,  $\tau_2$ , and a third time lag,  $\tau_3$ , each time lag being indicative of a time delay from one of said M sources to one of said N elements;

N is indicative of a number of elements in said array;

$\text{Cum} [x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3)]$  is a cumulant operator on arguments  $[x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3)]$ ;

$t$  is a variable representing time;

$x_i^*(t - \tau_1)$  represents a complex conjugate of one of said M signals from an  $i^{\text{th}}$  source at time  $t - \tau_1$ ;

$x_i(t - \tau_2)$  represents one of said M signals from an  $i^{\text{th}}$  source at time  $t - \tau_2$ ;

$\mathbf{x}(t)$  is a vector representation of said M signals; and

$\mathbf{x}^H(t - \tau_3)$  represents the Hermitian transpose of  $\mathbf{x}(t - \tau_3)$ .

5. A method in accordance with Claim 1 wherein said step of generating said hybrid separation matrix comprises performing a generalized eigenvalue analysis of said spatial fourth order cumulant matrix pencil.

6. A method in accordance with Claim 1 wherein  $M = N$ .

7. A method in accordance with Claim 1 wherein  $M < N$ .

8. A computer readable medium encoded with a computer program code for directing a processor to separate M signals provided by a Msources and received by an array comprising N elements, said program code comprising:

a first code segment for causing said processor to generate a hybrid separation matrix as a function of:

time differences between receipt of said M signals by said N elements;

a spatial fourth order cumulant matrix pencil;

a spatial correlation matrix; and,

steering vectors of said plurality of signals,

and,

a second code segment for causing said processor to multiply said separation matrix by a time series matrix representation of said M signals.

9. A computer readable in accordance with Claim 8 wherein the hybrid separation matrix is in accordance with the following equation:

$$\hat{w}_{j,hyb} = \left| \hat{v}_j^H \hat{K}_j^{-1} \hat{v}_j \right|^{-1} \hat{K}_j^{-1} \hat{v}_j; \text{ wherein,}$$

$v_j$  is the steering vector of the  $j^{th}$  signal;

$K_j$  is the noise spatial covariance matrix of the  $j^{th}$  signal.

10. A computer readable in accordance with Claim 8 wherein

said spatial fourth order cumulant matrix pencil is a function of a spatial fourth order cumulant matrix being a summation of steering vector outer products scaled by an individual source signal's fourth order cumulant; and,

said steering vector is indicative of respective phase delays between ones of said N elements.

11. A computer readable medium in accordance Claim 10 wherein said spatial fourth order cumulant matrix is in accordance with the following equation:

$$C_x^4(\tau_1, \tau_2, \tau_3) \equiv \sum_{i=1}^N \text{Cum} \left[ x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3) \right], \text{ wherein:}$$

$C_x^4(\tau_1, \tau_2, \tau_3)$  is said spatial fourth order cumulant matrix having a first time lag,  $\tau_1$ , a second time lag,  $\tau_2$ , and a third time lag,  $\tau_3$ , each time lag being indicative of a time delay from one of said M sources to one of said N elements;

N is indicative of a number of elements in said array;

$\text{Cum} [x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3)]$  is a cumulant operator on arguments  $x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3)$ ;

$t$  is a variable representing time;

$x_i^*(t - \tau_1)$  represents a complex conjugate of one of said M signals from an  $i^{\text{th}}$  source at time  $t - \tau_1$ ;

$x_i(t - \tau_2)$  represents one of said M signals from an  $i^{\text{th}}$  source at time  $t - \tau_2$ ;

$\mathbf{x}(t)$  is a vector representation of said M signals; and

$\mathbf{x}^H(t - \tau_3)$  represents the Hermitian transpose of  $\mathbf{x}(t - \tau_3)$ .

12. A computer readable medium in accordance with Claim 8, said program code further comprising:

a third code segment for causing said processor to perform a generalized eigenvalue analysis of said spatial fourth order cumulant matrix pencil.

13. A computer readable medium in accordance with Claim 8 wherein  $M = N$ .

14. A computer readable medium in accordance with Claim 8 wherein  $M < N$ .

15. A system for separating M signals provided by M sources, said system comprising:

a receiver for receiving said M signals and for providing received signals therefrom; and  
 a signal processor for receiving said received signals, generating a hybrid separation  
 5 matrix, and multiplying said separation matrix by a time series matrix representation of  
 said received signals, wherein:

said hybrid separation matrix is a function of time differences between receipt of  
 said M signals by said receiver, a spatial correlation matrix; steering vectors of  
 said M signals and a spatial fourth order cumulant matrix pencil.

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16. A system in accordance with Claim 15, wherein the hybrid separation matrix is in  
 accordance with the following equation:

$$\hat{w}_{j,hyb} = \left| \hat{v}_j^H \hat{K}_j^{-1} \hat{v}_j \right|^{-1} \hat{K}_j^{-1} \hat{v}_j; \text{ wherein,}$$

$v_j$  is the steering vector of the  $j^{th}$  signal;

15  $K_j$  is the noise spatial covariance matrix of the  $j^{th}$  signal.

17. A system in accordance with Claim 15 wherein said receiver comprises N  
 elements configured to form an array.

20 18. A system in accordance with Claim 15 wherein

said spatial fourth order cumulant matrix pencil is a function of a spatial fourth order  
 cumulant matrix being a summation of steering vector outer products scaled by an  
 individual source signal's fourth order cumulant; and,

25 said steering vector is indicative of respective phase delays between ones of said  
 N elements.

19. A system in accordance Claim 18 wherein said spatial fourth order cumulant matrix is in accordance with the following equation:

$$C_x^4(\tau_1, \tau_2, \tau_3) \equiv \sum_{i=1}^N Cum \left[ x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3) \right], \text{ wherein:}$$

$C_x^4(\tau_1, \tau_2, \tau_3)$  is said spatial fourth order cumulant matrix having a first time lag,  $\tau_1$ , a second time lag,  $\tau_2$ , and a third time lag,  $\tau_3$ , each time lag being indicative of a time delay from one of said M sources to one of said N elements;

N is indicative of a number of a number of elements in said array;

$Cum [x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3)]$  is a cumulant operator on arguments  $x_i^*(t - \tau_1) x_i(t - \tau_2) \mathbf{x}(t) \mathbf{x}^H(t - \tau_3)$ ;

$t$  is a variable representing time;

$x_i^*(t - \tau_1)$  represents a complex conjugate of one of said M signals from an  $i^{\text{th}}$  source at time  $t - \tau_1$ ;

$x_i(t - \tau_2)$  represents one of said M signals from an  $i^{\text{th}}$  source at time  $t - \tau_2$ ;

$\mathbf{x}(t)$  is a vector representation of said M signals; and

$\mathbf{x}^H(t - \tau_3)$  represents the Hermitian transpose of  $\mathbf{x}(t - \tau_3)$ .

20. A system in accordance with Claim 17 wherein  $M = N$ .

21. A system in accordance with Claim 17 wherein  $M < N$ .

22. In a method for recovering low SNR signals in an multi-signal and noise environment with a multi-sensor array wherein a separation matrix is applied to the multi-sensor array data, the improvement of forming the separation matrix with hybrid minimum mean squared error weights, wherein said weights are generated as a function of a spatial correlation matrix; steering vectors of said multiple signals and a spatial fourth order cumulant matrix pencil.

23. A method in accordance with Claim 22 wherein the number of said multiple signals is equal to the number of said multiple sensors in said array.

5 24. A method in accordance with Claim 22 wherein the number of said multiple signals is less than the number of said multiple sensors in said array.

10 25. A method for recovering an unknown signal from a composite signal containing the unknown signal and at least one interferer signal and noise, said method comprising the step of generating a separation matrix to suppress the at least one interferer signal and the noise, wherein the separation matrix is a function of the spatial correlation matrix of the unknown signal, a steering vector, and a spatial fourth order cumulant matrix pencil of the unknown signal and the at least one interferer signal.

15 26. A method in accordance with Claim 25 wherein said composite signal comprises M signals and is received on an N element array.

27. A method in accordance with Claim 26 wherein  $M = N$ .

28. A method in accordance with Claim 26 wherein  $M < N$ .